Conference Paper

Functional and Amylographic Properties of Physically-Modified Sweet Potato Starch

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Abstract

In general, native sweet potato starch has inferior characteristics such as it swells easily, does not gel firmly and low paste clarity. The characteristics of native sweet potato starch cause limitation in its utilization. This research aimed to study the effect of physically modified starch on the functional and amylographic properties of native sweet potato starch. The study used a descriptive method with 4 treatments and 2 replications: a) a native sweet potato starch, b) sweet potato modified starch by heat moisture treatment, c) sweet potato starch modified by annealing and d) sweet potato starch modified by pre-gelatinization. The results showed that all three treatments modified starches largely alter the functional and amylographic properties of native sweet potato starch. Heat moisture treated and annealed sweet potato had starches with decreased swelling volume, solubility, peak viscosity, and breakdown viscosity, increased pasting temperature and setback viscosity than its native starch. Pre-gelatinized sweet potato starch has lower bulk density, peak viscosity, breakdown viscosity, setback viscosity and increased swelling volume, solubility and water absorption capacity than its native starch.

Keywords: functional properties; amylographic properties; sweet potato starch; physically modified.

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1. Introduction

Starch, the main component of sweet potato tubers, accounts for around 50-80% of their dry weight [1]. Starch is the most abundant reserve carbohydrates among plants and also a major source of carbohydrate in the human diet, supplying mainly energy.

Sweet potato starch is widely used in the food industry as an ingredient in processed sweet potato products such as noodles, soups, sauces, snacks, and breads [2]. As the use of native sweet potato starch in the food system is comparatively limited. Native sweet potato starch (unmodified) has inferior characteristics such as it swells easily, does not gel firmly and low paste clarity. Some modifications are necessary to expand the range of application of sweet potato starch in food industry. Since the source of

starch affects its functional and amylographic properties even alter modification, it is necessary to investigate the functional and amylographic properties of modified sweet potato starch. Information about changes in functional and amylographic properties of starches caused by physical modification is helpful in understanding their application in food production.

Physical method of starch modification is a relatively easier process and safer in terms of health since it does not include chemicals. The molecular arrangement in a starch granule can be altered by various physical treatments. Annealing and heat moisture treatments (HMT) are two common physical means by which the treated starch can acquire modified properties without rupturing the granule. Annealing is generally carried out by heating granule starch with a large quantity of water at a temperature below the starch melting point, whereas HMT is carried out at limited moisture contents (18-27%) but at an elevated temperature [3]. These physical treatments can change certain starch properties using simple and environmentally safe processes. The physical properties of a heat moisture treated starch depend on the starch origin and treatment used. Collado and Corke [4] treated a sweet potato starch, and found that the starch paste became short, sheer-stable and the starch gel exhibited marked increases in hardness and adhesiveness, whereas annealing increased the surface hardness of mung bean starch gels and changes pasting curves [5].

Pre-gelatinized starch is a common type of physically modified starch with wide applications, especially in food industry. Pre-gelatinized starch, also referred to "pre-gel" or "instant starch", is generally produced by drum drier, spray drier, and to a lesser extent by extruder [6]. Depending on the method, condition and source of starch, the produced pre-gelatinized starch has different properties [7]. Pre-gelatinized starch produced using drum drier had the following properties such as no granular structure, low crystalline structure, high cold water viscosity, and high water solubility and absorption. The results support the notion that the integrity of starch granules has a great contribution to the rheology of starch paste [8].

The objective of the present research was to determine the impact of HMT, annealing and pre-gelatinization on functional and amylographic properties of sweet potato starch. The studies involve isolation of starch, modification of starch, and determination of functional properties, such as bulk density, swelling volume and solubility, water absorption capacity and amylographic characteristics such as pasting temperature, peak viscosity, hot paste viscosity, final viscosity, breakdown, and set back.

2. Materials and Method

2.1. Materials

This research used white sweet potato tubers IR Melati (harvested at age of 3-4 months). Chemicals for analysis was distilled water, α-amylase enzyme (activity of 900 U/mg), Na - phosphate buffer 0.05M (pH 7), 3.5-dinitrosalicylic, Na-K-tartaric, NaOH, HCl, as well as chemicals for proximate analysis.

2.2. Isolation of starch from sweet potato

Sweet potatoes were washed, peeled and cut into cubes soaked in water for 10 min, and then blendered in a high speed blender. The resulting slurry was passed through a 100-mesh sieve. The precipitated solid were suspended in distilled water (1:2) and precipitated again. This procedure was repeated until the color of the precipitated starch was pure white (3 x). The starch slurry was dried at 45 °C for 24 h in a drying oven. Then, it was milled and passed through a 100-mesh sieve.

2.3. Modification

Starch was annealed by dispersing starch samples in water (with ratio of 1:4 starch to water). The mixture was then heated at 50 °C for 24 h. The residue was stored at freezer. Heat–moisture treatment was conducted by adding water to starch sample (100 g) to achieve various moisture contents 30% wb and equilibrated at 4 °C for 24 h. The mixture was heated in air tight glass bottles at 110 °C in an air convection oven for 8 h. The starch samples were then dried at 50 °C overnight for further analysis. Heat–moisture treated starches were abbreviated as HMT with subscripts indicating the amount of moisture added. Pre-gelatinized sweet potato starch is made by mixing starch with water at a ratio of 1:1, then stirred until homogeneous. The starch slurry was drum dried at 3 atm (135 °C), 2 rpm and a cylinder spacing of 2.5 mm. The resulting flakes were milled in a disc mill and sieved with a 100-mesh sieve [9].

2.4. Bulk density

A 50 g flour sample was put into a 100 ml graduated cylinder. The cylinder was tapped continuously until a constant volume was obtained. The bulk density (g cm^{-3}) was calculated as weight of flour (g) divided by flour volume (cm^3) [10].

2.5. Swelling volume and solubility

Swelling volume was determined by weighing 0.35 g (d.b.) sweetpotato starch into sentrifuge tubes to which 12.5 ml of water was added. The tubes were equilibrated at 25 °C for 5 min, transferred to a 92.5 °C waterbath and mixed for 30 min. Samples were cooled in ice water for 1 min, placed in a 25 °C bath for 5 min and centrifuged at 1000 g for 15 min. The height of the gel was measured and converted to volume of gel per unit dry weight of the sample [11].

2.6. Water absorption capacity (WAC)

One gram of the flour was mixed with 10 ml of water in a centrifuge tube and allowed to stand at room temperature (26 ± 2 °C) for 1 h. It was then centrifuged at 200 g for 30 min and volume supernatant measured. Water absorption capacities were calculated as ml of water absorbed per gram of flour [12].

2.7. Amylographic properties

The pasting properties of the starches were evaluated with a Rapid Visco Analyser (RVA-4, Newport Scientific, Warriewood, Australia) using RVATM Crosslinked and Substituted Method, No. 9, Version 4 (Newport) [13]. Starch (3 g, adjusted to 14% moisture basis) was weighed directly in the aluminum RVA sample canister, and distilled water was added to make total constant sample weight of 28 g. A programmed heating and cooling cycle was used respectively the samples were held at 50 °C for 1 min, heated to 95 °C for 3.7 min, held at 95 °C for 2.5 min before cooling to 50 °C in 3.8 min, and then held at 50 °C for 2 min. Parameters recorded were pasting temperature (PT); peak viscosity (PV); hot paste viscosity (HPV) (minimum viscosity at 95 °C); final viscosity (FV) (final viscosity at 50 °C); breakdown (BD) (=PV–HPV); and set back (SB) (=FV–HPV). All measurements were replicated twice.

3. Result and Discussion

3.1. Functional properties

The bulk density of native sweet potato, HMT and annealed starch as shown in Table 1 were not much different. This indicates that HMT and annealing did not alter bulk density of sweet potato starch.

Bulk Density of pre-gelatinized sweet potato starch is the smallest compared to other treatments of sweet potato starch which is 0.50 g/ml. Small values of bulk

Table 1: Functional Properties of Native and Modified Sweet Potato Starch*.

Sweet Potato Starch	Bulk Density (g/ml)	Swelling Volume (ml/g)	Solubility (%)	Water Absorption Capacity (g/g)
Native	0.65	2.57	2.96	2.32
HMT	0.66	1.67	1.97	1.29
Annealed	0.63	1.68	1.84	2.98
Pre-gelatinized	0.50	3.15	4.23	5.42

* average of 2 replicants

density on pre-gelatinized sweet potato starch is caused by the increasing levels of sweet potato starch gelatinization, so the porosity of the starch increases. Small bulk density value means that the material requires a large volume for a small amount of material, or in other words the more bulky these materials.

HMT starch have a lower swelling volume and solubility than native sweet potato starch which is 1.67 ml/g and 1.97%, respectively. The decrease in swelling volume may be caused by the interaction of amylose - amylose, amylopectin and amylose - amylopectin - amylopectin became stronger, resulting in more rigid starch granules after hydrothermal process. A decrease in swelling volume and solubility of HMT starch granules also caused a decrease in stability due to the release of the double helix bonds contained in the crystalline starch granules [13]. HMT treatment not only causes changes in the crystalline regions but also in the amorphous regions of starch granules. Amylose content and starch chain length is a factor that greatly affects the physical properties of the final product. Kurahashi and Hizukuri [14] reported that amylose - lipid complexes formed after the HMT and this can also lead to a decrease in swelling volume and solubility.

A decrease in swelling volume and solubility of HMT sweet potato starch can also be caused by the decrease in the number of molecules of amylopectin and increase of amylose due to the increasing number of degraded amylopectin molecules [15]. Further, Tester and Morrison [16] explain that amylopectin is a major factor that plays a role in controlling the development of starch granules.

Annealed sweet potato starch also has a swelling volume and lower solubility than native starch, which is 1.68 ml/g and 1.84%, respectively. This is caused by the rearrangement of the molecular structure of the starch granules. Eerlingen et al. [17] explain the decline in the volume of starch swelling caused by changing in annealing amorphous amylose forming helix structure; thus, this increase interaction between amylose chains and changes in the interaction between crystalline and amorphous regions during the annealing process.

Pre-gelatinized sweet potato starch has a swelling volume and higher solubility than native sweet potato starch which is 3.15 ml/g and 4.23%. Increase swelling and

solubility volume is related to the increasing amount of amylose and amylopectin leaching of the starch granules. Tan and Chinnaswamy [18] explained that the increase in swelling volume and solubility may be caused by disorganization macromolecular level and type of starch degradation. The higher the degree of gelatinization sweet potato starch, the higher the level of disorganization so increase the molecular starch swelling volume and solubility of the pre-gelatinized sweet potato flour.

Swelling volume is also associated with water absorption capacity of the sweet potato starch. Swelling volume is influenced by the ability of starch to bind water molecules through hydrogen bond formation. After gelatinization, hydrogen bonding between starch molecules was cut-off and replaced by hydrogen bonding with water. Rapid swelling of the starch granules rupture caused by intermolecular hydrogen bonding in the area of amorphous regions occurs at temperatures below 70 °C [19]. This may explain that the higher the water absorption capacity, the higher the swelling volume of sweet potato starch.

Water absorption capacity illustrates the amount of water available for gelatinization. Low water absorption capacity is desired in the manufacture of pulp [20]. According to Hodge and Osman [21], flour that has high water absorption capacity has more hydrophilic group. Furthermore, Hoover and Sosulski [22] explains that the difference in water absorption capacity of the material may be caused by differences in the level of binding of hydroxyl groups that form hydrogen bonds and covalent bonds between starch chains.

HMT sweet potato starch has a water absorption capacity which is lower than the water absorption capacity of the native sweet potato starch, namely 1.29 g/g. This indicates that there was a decline during treatment HMT hydrophilic properties. Annealed starch increased slightly compared to the water absorption capacity of the native starch. Increased water absorption capacity can be caused parts of amorphous experienced little development and few hydrogen bonding between the amorphous and crystalline broke [23].

Pre-gelatinized sweet potato starch has a water absorption capacity of 5.42 g/g. This value is higher than the water absorption capacity of the native sweet potato starch and the other modified sweet potato starch. The higher the degree of gelatinization of the starch, the higher the water absorption capacity of the starch. Gelatinized starch which has a hydrophilic group is more capable to bind with water and flour porosity also facilitates the absorption of water [24]. BeMiller and Whistler [25] stated that starches undergo gelatinization will lose crystallinity and increased ability to bind water. Increased water absorption capacity can also be caused by the denaturation of the protein that produces an amino acid residue that has the ability to bind with water.

Table 2: Amylography properties native and modified sweet potato starch*.

Sweet Potato Starch	PT (°C)	PV (cP)	HPP (cP)	BD (cP)	FV (cP)	SB (cP)
Native	75,23	2180,41	1643,76	536,65	2010,11	366,35
HMT	85,02	1150,54	1139,71	10,83	1602,32	462,61
Annealing	86,62	1281,81	1170,12	111,69	1701,87	420,06
Pre-gelatinized	ND	1680,41	1543,76	136,65	1860,11	316,35

PT = Pasting Temperature, PV = Peak Viscosity, HPP = Hot Paste Viscosity, BD = Breakdown, FV = Final Viscosity, SB = Setback
*average of 2 replications

3.2. Amylograph pasting properties

Analysis of rheological properties of sweet potato starch was done by using a Rapid Visco Analyzer (RVA). RVA is more practical to use because the measurement time is shorter and fewer samples required. Measurements of amylography properties of native sweet potato starch and modified sweet potato starches using RVA can be seen in Table 2.

In Table 2 it can be seen that the sweet potato starch by both means of HMT and annealed starch have pasting temperature higher than native starch which were 85.02°C and 86.62 °C, respectively. An increase in the pasting temperature of HMT and annealed sweet potato starch indicates that the energy required to break bonds between and inter molecular hydrogen in the sweet potato modified starch granule is greater than the native starch. This can happen if the rearrangement of amylose and amylopectin molecules in the granules during the modification process leads to increased stability of the molecular interactions within starch granules. Results of this study are supported by the results of other studies. Some studies indicate that HMT modification can improve the pasting temperature of starch include new cocoyam starch [26], and white sorghum starch [13].

Pasting temperature on pre-gelatinized sweet potato starch was not detected using RVA instrument because starch has been instantaneous and went straight up in the initial viscosity measurement. Pre-gelatinized sweet potato starch already damaged starch granules, making it easy to absorb water and when mixed with water directly increased viscosity [27].

Peak viscosity is the viscosity of the batter on the cusp of the heating process or condition in which the starch granules reach the maximum so that the next development would be broken. This parameter can be used as an indicator of ease when cooked, and also shows the strength of the dough that is formed of gelatinization during processing in food applications. The decrease in the peak viscosity indicates that there is also a decrease in the ability to inflate, and polymer was separated during heating (amylosa leaching).

Peak viscosity of HMT sweet potato starch is lower compared with native starch that is 1150.54 cP. This decrease in peak viscosity showed a decrease in water absorption capacity by the starch granules. Starches that have high water absorption capacity will experience also high swelling that result in high peak viscosity pastes. Excessive swelling of the starch granules will be followed by the decay of amylose molecules in the granules as a result of its inability to withstand the pressure. Likewise for annealed sweet potato starch also showed that the peak viscosity was lower than its native sweet potato starch.

Peak viscosity of pre-gelatinized starch was lower than native starch 1680.41 cP. According to Lai [28], the low peak viscosity of pre-gelatinized starch was caused by amylose starch molecules bind very strongly. Parameter of hot paste viscosity and breakdown is related to each other because of the breakdown is the difference between peak viscosity with hot paste viscosity. Impairment hot paste viscosity is generally followed by an increase in breakdown. However, in certain circumstances a hot paste viscosity decrease is not always accompanied by an increase in breakdown. If the hot paste viscosity and peak viscosity decreases proportionally then pasta breakdown will likely to remain.

A hot paste viscosity index of the ease of cooking and reflected weakness in the granules swells. Breakdown is a decrease of value when the suspension of starch is heated at a temperature of 95 °C. Breakdown shows dough stability during the cooking process.

In Table 3 it can be seen that a good sweet potato starch modified by HMT, annealling and pre-gelatinization have a hot paste viscosity and its breakdown is lower than that of native starch. This indicates that all three treatment starch modification can improve the stability of the starch to heat and stirring. HMT modified starch improved stability against heat and this caused a shift in the type of starch crystallization which leads to increased stability of the granules. HMT potato starch shifting crystallization type of type B to type A, where the starch with type A crystal has a double helix arrangement that tighter so it is more resistant to heat treatment [29].

A decrease in hot paste viscosity and breakdown of annealing sweet potato starch was due to the increased regularity of the crystalline matrix and the formation of amylose-lipid complexes that degrade granule swelling capacity and improve the stability of the paste during heating. When compared between the three types of modified starch, HMT sweet potato starch has the most excellent stability against heat and stirring. This can be seen from its low viscosity grades of sweet potato starch breakdown (10.83 cP).

Retrogradation tendency can be seen from the final viscosity and setback. During cooling, the joining of return between molecules mainly amylose starch produce the gel structure and its viscosity increases to a final viscosity. Increased viscosity during

cooling determines the tendency of merging back starch product that reflects the tendency for retrogradation [30]. However, if the tendency to rejoin is weak, hydrogen bonds are formed slowly.

Setback or change in viscosity during cooling is obtained from the difference between a cold paste viscosity and hot paste viscosity. The higher the value of setback the higher is the tendency to form a gel (increase the viscosity) during cooling. The high value of setback indicate a tendency for the occurrence of retrogradation. It is based on the understanding that the establishment of a network retrogradation microcrystals of molecules that bind amylosa molecules back each other or with amylopectin branching outside the granules after the pasta is cooled [31]. According to Beta and Corke [32], the setback can be used to measure the ability of re-crystallization of starch which has undergone gelatinization during cooling.

In Table 3 it can be seen that the HMT and annealedstarch increased viscosity setback compared with native starch. Setback of HMT sweet potato starch was the highest (462.61 cP). This suggests that the starch has a high tendency to retrogradation.

Modified starch with high setback has the ability to form a gel, which is good. With a high starch setback prone to retrogradation, it is better to be used as a raw material of vermicelli [33]. According to Stute et al. [34], when the starch granules has been modified by annealing, it will form stiff texture and will significantly increase in viscosity of cold pasta.

Pre-gelatinized sweet potato starch decreased setback viscosity than native starch. At the time of gelatinization, amylose out of the starch granules and can form amylose - fat complexes. This complex formation can also reduce the tendency of amylose to bind, form a gel and being retro-gradation thus inhibiting the hardening rate during heating [35]. Decrease setback is important for the characteristics of flour to be used in the manufacture of weaning food [36].

4. Conclusion

Three treatments modified starches (HMT, annealing, pre-gelatinization) largely alter the functional and amylography properties of native sweet potato starch. Heat moisture treated and annealed sweet potato starches decreased swelling volume, solubility, peak viscosity, breakdown viscosity and increased pasting temperature and setback viscosity than its native starch. Pregelatinized sweet potato starch decreased bulk density, peak viscosity, breakdown viscosity, setback viscosity and increased swelling volume, solubility and water absorption capacity than its native starch. Pregelatinized starch has the highest swelling volume (3.15 ml/g), solubility (4.23%), and water absorption capacity (5.42 g/g) and the lowest bulk density (0.50 g/ml) than the

others. HMT starch has the lowest peak viscosity (1150.54 cp), breakdown (10.83 cp) and the highest setback (462.61 cp).

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